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THERMOPHYSICAL AND ELECTRONIC PROPERTIES INFORMATION ANALYSIS CENTER (TEPIAC)

A Continuing Systematic Program on Tables of Thermophysical and Electronic Properties of Materials

February 1977

C. Y. HO

Center for Information and Numerical Data Analysis and Synthesis
Purdue University
West Lafayette, Indiana 47906

Final Report—Contract DSA900-76-C-0860

Approved for public release; distribution unlimited.

Prepared for

ARMY MATERIALS AND MECHANICS RESEARCH CENTER
Watertown, Massachusetts 02172

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This Final Report describes the activities and accomplishments of the Thermophysical and Electronic Properties Information Analysis Center (TEPIAC) in the period 1 October 1975 to 31 December 1976. TEPIAC's activities reported herein include literature search, acquisition, and input of source information; document review and codification and substance classification; operation of a computerized information storage and retrieval system; preparation and publication of the Thermophysical Properties Research Literature Retrieval Guide Supplement; data extraction and compilation; data evaluation, correlation, analysis, synthesis, and generation of →

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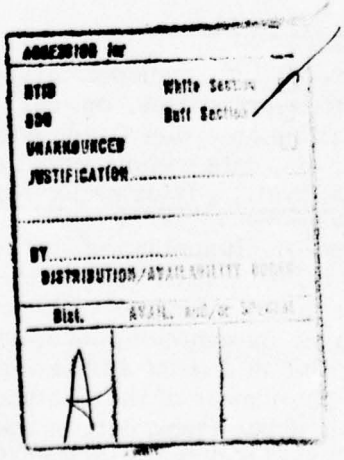
recommended values; preparation and publication of the Thermophysical Properties of Matter - The TPRC Data Series, state-of-the-art reports, and critical reviews; technical and bibliographic inquiry services; and current awareness and promotion efforts. TEPIAC covers 14 thermophysical properties and 22 electronic (including also electrical, magnetic, and optical) properties and property groups of nearly all materials at all temperatures. During this 15-month contractual period, the Center has screened 1,000,000 abstracts, scrutinized 112, 800 abstracts, identified 21,974 pertinent references, acquired 14,894 research documents, reviewed, coded, and catalogued 8,853 documents, extracted and compiled 4,897 sets of property data from 1,855 data source documents by processing 3,310 research documents, and responded to 603 inquiries from 40 states and the District of Columbia and 17 foreign countries. Furthermore, during this period Volume 12 of the Thermophysical Properties of Matter - The TPRC Data Series was published, and Volume 13 of the Data Series, Volume 6 Supplement, and three special state-of-the-art reports have been completed. The published Volume 12 entitled "Thermal Expansion - Metallic Elements and Alloys" contains 1,440 pages, presents 4,253 sets of data on 64 elements, 94 intermetallic compounds, 125 binary alloy systems, and 70 groups of multiple alloys, with a total of 672 different materials, and cites 781 references to data sources and 91 references to the text on theories, estimation methods, and measurement techniques for thermal expansion. The completed Volume 13 entitled "Thermal Expansion - Nonmetallic Solids" contains 1,800 pages, presents 4,990 sets of data on 11 nonmetallic elements, 23 groups of graphites, 61 simple oxides, 76 complex oxides, 48 salts, 127 nonoxide compounds, 5 groups of ceramics, 11 groups of cermets, 15 groups of glasses, 60 polymers, and 15 groups of composites, with a total of 815 different materials, and cites 1112 references to data sources and 101 references to the text. The completed Supplement to Volume 6 (Specific Heat - Nonmetallic Liquids and Gases) contains 169 pages, presents 726 sets of data on 103 inorganic compounds and 204 organic compounds, and cites 878 references. The completed three special state-of-the-art reports contain a total of 479 pages. Eight issues of the "Thermophysics and Electronics Newsletter" have been released during this period to a circulation list of 3,900 TEPIAC users and potential users totaling 31,200 copies distributed. The TEPIAC staff members participated in seven conferences and meetings, and seven foreign scientists from four countries have visited TEPIAC during this period.



SUMMARY

The Thermophysical and Electronic Properties Information Analysis Center (TEPIAC) is a Department of Defense Information Analysis Center operated by the Center for Information and Numerical Data Analysis and Synthesis (CINDAS) of Purdue University under contract with the Defense Supply Agency (DSA) and under the technical direction of the Army Materials and Mechanics Research Center (AMMRC). The objective of TEPIAC operations is to increase the productivity of scientists, engineers, and technicians engaged in scientific and engineering programs for the Department of Defense by maintaining a comprehensive and up-to-date national data base on thermophysical and electronic (including also electrical, magnetic, and optical) properties of materials for use by the entire DoD community and providing authoritative data and information analysis services. Its major functions are to search, collect, review, evaluate, analyze, synthesize, and condense the available data and information from worldwide sources on the various properties of materials and to disseminate the resulting data and information both through formal publications to the general users at large and through technical and bibliographic inquiry services to the individual users directly.

TEPIAC covers 14 thermophysical properties and 22 electronic (including also electrical, magnetic, and optical) properties and property groups of nearly all materials at all temperatures.

This Final Report describes the activities and accomplishments of TEPIAC in the period 1 October 1975 to 31 December 1976. TEPIAC's activities reported herein include literature search, acquisition, and input of source information; document review and codification and substance classification; operation of a computerized information storage and retrieval system; preparation and publication of the Thermophysical Properties Research Literature Retrieval Guide Supplement; data extraction and compilation; data evaluation, correlation, analysis, synthesis, and generation of recommended values; preparation and publication of the Thermophysical Properties of Matter - The TPRC Data Series, state-of-the-art reports, and critical reviews; technical and bibliographic inquiry services; and current awareness and promotion efforts.

TEPIAC represents one of the most cost-effective Information Analysis Centers when evaluated on output and input volume per budgeted dollar. During this 15-month contractual period, the Center has screened 1,000,000 abstracts, scrutinized 112,800 abstracts, identified 21,974 pertinent references, acquired 14,894 research documents, reviewed, coded, and catalogued 8,853 documents, extracted and compiled 4,897 sets

of property data from 1,855 data source documents by processing 3,310 research documents, and responded to 603 inquiries from 40 states and the District of Columbia and 17 foreign countries. Furthermore, during this period Volume 12 of the Thermophysical Properties of Matter - The TPRC Data Series was published, and Volume 13 of the Data Series, Volume 6 Supplement, and three special state-of-the-art reports have been completed. The published Volume 12 entitled "Thermal Expansion - Metallic Elements and Alloys" contains 1,440 pages, presents 4,253 sets of data on 64 elements, 94 intermetallic compounds, 125 binary alloy systems, and 70 groups of multiple alloys, with a total of 672 different materials, and cites 781 references to data sources and 91 references to the text on theories, estimation methods, and measurement techniques for thermal expansion. The completed Volume 13 entitled "Thermal Expansion - Nonmetallic Solids" contains 1,800 pages, presents 4,990 sets of data on 11 nonmetallic elements, 23 groups of graphites, 61 simple oxides, 76 complex oxides, 48 salts, 127 nonoxide compounds, 5 groups of ceramics, 11 groups of cermets, 15 groups of glasses, 60 polymers, and 15 groups of composites, with a total of 815 different materials, and cites 1112 references to data sources and 101 references to the text. The completed Supplement to Volume 6 (Specific Heat - Nonmetallic Liquids and Gases) contains 169 pages, presents 726 sets of data on 103 inorganic compounds and 204 organic compounds, and cites 878 references. The completed three special state-of-the-art reports contain a total of 479 pages. Eight issues of the "Thermophysics and Electronics Newsletter" have been released during this period to a circulation list of 3,900 TEPIAC users and potential users totaling 31,200 copies distributed. The TEPIAC staff members participated in seven conferences and meetings, and seven foreign scientists from four countries have visited TEPIAC during this period.

PREFACE

This Final Report was prepared by the Thermophysical and Electronic Properties Information Analysis Center (TEPIAC), a Department of Defense Information Analysis Center. This Center is operated by the Center for Information and Numerical Data Analysis and Synthesis (CINDAS), Purdue University, West Lafayette, Indiana, under Contract No. DSA900-76-C-0860 with the Defense Supply Agency (DSA), Alexandria, Virginia, with Mr. J. L. Blue being the Program Manager, and under the technical direction of the Army Materials and Mechanics Research Center (AMMRC), Watertown, Massachusetts, with Mr. Samuel Valencia being the Contracting Officer's Technical Representative. The Contract was issued by the Defense Electronics Supply Center, Dayton, Ohio, with Mr. M. P. Tabor being the Contracting Officer.

This Final Report covers the contractual period from 1 October 1975 to 31 December 1976, and was submitted by the author in January 1977 to fulfill the contractual requirement (Item No. 0002, Sequence No. A002).

The work reported herein is credited to the collective efforts of the entire staff of the Thermophysical and Electronic Properties Information Analysis Center. Dr. Y. S. Touloukian has been the principal investigator and program director.

This report has been reviewed and is approved.

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SECTION I

INTRODUCTION

The Thermophysical and Electronic Properties Information Analysis Center (TEPIAC) is a Department of Defense Information Analysis Center operated by the Center for Information and Numerical Data Analysis and Synthesis (CINDAS) of Purdue University. The objective of TEPIAC operations is to increase the productivity of scientists, engineers, and technicians engaged in scientific and engineering programs for the Department of Defense by maintaining a comprehensive and up-to-date national data base on thermophysical and electronic (including also electrical, magnetic, and optical) properties of materials for use by the entire DoD community and by providing authoritative data and information analysis services. Its major functions are to search, collect, review, evaluate, analyze, synthesize, and condense the available data and information from worldwide sources on the various properties of materials and to disseminate the resulting data and information both through formal publications to the general users at large and through technical and bibliographic inquiry services to the individual users directly.

TEPIAC's activities and tasks include literature search, acquisition, and input of source information; document review and codification; substance classification and organization; operation of a computerized information storage and retrieval system; data extraction and compilation; data evaluation, correlation, analysis, synthesis, and generation of recommended values; preparation and publication of handbooks, data books, retrieval guides, state-of-the-art reports, and critical reviews; technical and bibliographic inquiry services; and current awareness and promotion efforts. TEPIAC's accomplishments in all its activities and tasks in performance of this contract for the contractual period from 1 October 1975 to 31 December 1976 are detailed in this Final Report.

SECTION II

SCIENTIFIC DOCUMENTATION ACTIVITIES

In order to maintain a comprehensive and up-to-date national data base on thermophysical, electronic, electrical, magnetic, and optical properties of materials and to be able to provide authoritative information and data to the users with instant retrieval capability, TEPIAC has maintained a systematic program of literature search, acquisition, review, codification, classification, organization, and storing the resulting information in a computerized information storage and retrieval system. The various phases of activities in this program are discussed below.

1. LITERATURE SEARCH, ACQUISITION, AND INPUT OF SOURCE INFORMATION

The fourteen thermophysical properties under TEPIAC cognizance of information and data in all pertinent subject areas are as follows:

1. Thermal conductivity
2. Accommodation coefficient
3. Thermal contact resistance
4. Thermal diffusivity
5. Specific heat at constant pressure
6. Viscosity
7. Emittance
8. Reflectance
9. Absorptance
10. Transmittance
11. Solar absorptance to emittance ratio
12. Prandtl number
13. Thermal linear expansion coefficient
14. Thermal volumetric expansion coefficient

Originally two more properties (diffusion coefficient and surface tension) had been monitored, but these were dropped in mid-1970.

The fifteen specific electronic, electrical, magnetic, and optical properties and seven property groups under TEPIAC cognizance of information and data in all pertinent subject areas are as follows:

Properties

1. Absorption coefficient
2. Dielectric constant
3. Dielectric strength
4. Effective mass
5. Electric hysteresis
6. Electrical resistivity
7. Energy bands
8. Energy gap
9. Energy levels
10. Hall coefficient
11. Magnetic hysteresis
12. Magnetic susceptibility
13. Mobility
14. Refractive index
15. Work function

Property Groups

16. Electron emission properties
    a. Field emission
    b. Photoemission
    c. Secondary emission
    d. Thermionic emission
17. Luminescence properties
    a. Cathodoluminescence
    b. Electroluminescence
    c. Mechanical luminescence
    d. Photoluminescence
    e. Thermoluminescence
18. Magnetoelectric properties
    a. Ettingshausen effect
    b. Magnetoresistance
    c. Nernst effect
    d. Shubnikov-de Haas effect
19. Magnetomechanical properties
    a. Anisotropy energy
    b. Magnetostriction
20. Photoelectronic properties
    a. Dember effect
    b. Photoconductivity
    c. Photomagnetic effect
    d. Photopiezoelectric effect
    e. Photovoltaic effect
21. Piezoelectric properties
    a. Piezoelectric effect
    b. Pyroelectric effect
22. Thermoelectric properties
    a. Peltier effect
    b. Seebeck effect
    c. Thomson effect

As to material coverage in this documentation phase of the program, TEPIAC covers nearly all matter, which is far more than what is required by the contract. The materials required by the contract to be covered for thermophysical properties include, as a minimum, metals and metal alloys, ceramics, cermets, intermetallics, polymers, and composites, and those for electronic (including also electrical, magnetic, and optical) properties to be given priority coverage include elements, inorganic compounds, alloys, intermetallics, glasses, ceramics, cermets, applied coatings, polymers, composites, and systems.

The strategy of literature search has been to use both the abstracting journals and technical journals. The top ten high-yield technical journals for thermophysical properties in the past five years are noted below:

1. Physical Review
2. Journal of Chemical Physics
3. Journal of Applied Physics
4. Russian Journal of Physical Chemistry
5. Soviet Physics - Solid State

6. Inorganic Materials (USSR)
7. Physica Status Solidi
8. Applied Optics
9. High Temperature (USSR)
10. Solid State Communications

The top ten high-yield technical journals for electronic properties in the past five years are as follows:

1. Journal of Applied Physics
2. Soviet Physics - Semiconductors
3. Physica Status Solidi
4. Physical Review
5. Soviet Physics - Solid State
6. Solid State Communications
7. Physics Letters
8. Journal of Physical Society of Japan
9. AIP Conference Proceedings
10. Japanese Journal of Applied Physics

Recent approximate statistics shows that references on thermophysical and electronic properties come from the following major sources:

	Percent		Percent
TEPIAC journal subscriptions	10	Government reports (NTIS)	2
Purdue journal subscriptions	65	Ph. D. dissertations	1.5
Library of Congress	10	M. S. theses	0.5
Government reports (DDC)	6	Other sources	5
		Total	100.0

This list shows that scientific and technical open literature constitutes about 92 percent of the total references and government reports constitute only about 8 percent.

The pertinent references are identified partly by monitoring four abstracting journals to cover the open literature and four government abstracting journals to cover the government report literature. These are:

1. Chemical Abstracts
2. Physics Abstracts
3. Electrical and Electronics Abstracts
4. Dissertation Abstracts International
5. Scientific and Technical Aerospace Reports (NASA)
6. Technical Abstracts Bulletin (DDC)
7. U. S. Government Reports Announcements (NTIS)
8. Technical Translations (NTIS)

In monitoring these abstracting journals, computer-screened inputs have been used. Close to one million abstracts were screened by computer using carefully designed search logics. These basic sources and other minor sources yielded 112,800 hits in this 15-month contractual period. These 112,800 potentially good entries were further

scrutinized manually to yield 6,200 pertinent references on thermophysical properties and 21,774 references on electronic properties in this 15-month period. This and other statistical data showing TEPIAC's scientific documentation accomplishments in this period are presented in Table I.

In addition to the basic sources, TEPIAC has searched certain specialized sources such as special bibliographies, compendia, conference proceedings, and symposium volumes. Of particular note is the Kobe Affiliate* of CINDAS at Kobe, Japan, who has served a very important input function for Far Eastern literature. Furthermore, TEPIAC has continued to develop its cooperative working arrangements on the exchange of research results and information with major national and international laboratories and institutions engaged in thermophysical and/or electronic properties research. Through these highly developed procedures and arrangements, TEPIAC has a high level of confidence in regard to completeness of its input of source information.

TEPIAC's specialized holdings, which number 77,870 on thermophysical properties and 67,043 on electronic properties as of 31 December 1976 as shown in Table I, constitute a unique national asset and are assuming increasing importance for rapid access to the world literature on thermophysical and electronic properties. Many of these research documents, though readily available from TEPIAC, are very difficult to obtain elsewhere especially in the cases of foreign literature and special publications of limited distribution. It is our experience that literature retrieval programs which yield only bibliographies as their end product are becoming increasingly less useful because of the difficulty and time lapse involved in procuring the cited documents. To remedy this situation, TEPIAC has long been supplementing the practice of submitting bibliographic responses to literature search requests with copies of the actual documents in the form of standard microfiche or hard copy.

2. DOCUMENT REVIEW AND CODIFICATION AND SUBSTANCE CLASSIFICATION

As each pertinent research document was received, it was immediately microfiched and then thoroughly reviewed. Pertinent information was extracted from the document with respect to the particular property measured or treated and the temperature range, the substance tested and its physical state, the subject coverage of the document, and the language used. All these except the substance name were translated into mnemonic code letters, and the substance was assigned a substance number according to an established substance classification scheme. The code letters, substance number, and document

* This CINDAS' overseas affiliate is supported through other sources.

TABLE I. STATISTICAL SUMMARY OF SCIENTIFIC DOCUMENTATION ACCOMPLISHMENTS

Thermophysical Properties

	Total as of 30 Sept. 1975	This Period	Total as of 31 Dec. 1976
Potential abstracts further scrutinized	---	24,800	---
Documents identified (references in system)	79,400	6,200	85,600
Documents on hand (microfiches and hard copies)	72,561	5,309	77,870
Documents reviewed, coded, and catalogued	72,585	815[a]	73,400
Codification entries on all properties	290,945	2,447	293,392

Electronic Properties

	Total as of 30 Sept. 1975	This Period	Total as of 31 Dec. 1976
Potential abstracts further scrutinized	---	88,000	---
Documents identified (references in system)	78,626	21,774	100,400
Documents on hand (microfilms, microfiches, and hard copies)	57,458[b]	9,585	67,043
Documents reviewed, coded, and catalogued	58,771[b]	8,038	66,809
Codification entries on all properties	174,208[c]	57,742	231,950

[a] Work in this area was suspended in 1976 in order that the staff could overhaul the bibliographic information system and magnetic tape search files.

[b] Includes 49,300 documents from former EPIC (Hughes Aircraft Co.).

[c] Includes estimated 127,000 code lines from former EPIC (Hughes Aircraft Co.).

number were recorded on a specially designed Coding Form, and were processed subsequently by computer for storage and retrieval, and also for publication of the Research Literature Retrieval Guides. The code letter designations for codification of literature on thermophysical and electronic properties are given in Tables II and III, respectively. Detailed codification procedures for literature on electronic properties had already been reported in a previous Final Report which was published in January 1974 as AMMRC CTR 74-4 (AD 774 852), and those for literature on thermophysical properties followed the established procedures for the past nineteen years.

As shown in Table I, in this 15-month contractual period 8,038 documents on electronic properties were reviewed, coded, and catalogued, and the coded information was processed by computer. Approximately 50 percent of the documents on electronic properties were coded from abstracts.

For thermophysical properties the review, coding, and cataloguing activities were suspended in 1976 in order that the staff could completely overhaul the bibliographic information system, which involved, among other things, the generation of a unique computerized material index, the complete editing of the various segments of the bibliographic data base for complete internal consistency as well as compatibility with the new bibliographic data base on electronic properties. These improvements will result in a more efficient codification and search operation and will enable putting the entire bibliographic data base on magnetic tape. Due to the above diversion of efforts, only 815 documents on thermophysical properties were reviewed, coded, and catalogued, as indicated in Table I.

For thermophysical properties, the technical coding of the 815 documents yielded 2,447 codification entires in the computerized documentation file on the 14 properties, making a total of 293,392 codification entries in the file as of 31 December 1976. For electronic properties, the technical coding of 8,038 documents yielded 57,742 codification entries in the computerized documentation file on the 22 properties, making a total of 231,950 codification entries as of 31 December 1976. Table IV shows the percentages of codification entries of the various properties with respect to the total number of entries. It is noted that the percentages of most of the properties remain fairly constant over the years.

The organization of the thermophysical and electronic properties information is by substance, and thus a sound substance classification scheme which can properly accommodate all substances and materials is very important. The established substance classification scheme has been designed to accommodate substances and materials into

TABLE II. CODE LETTER DESIGNATIONS FOR CODING OF LITERATURE ON THERMOPHYSICAL PROPERTIES

Property:	A - Thermal conductivity
	B - Accommodation coefficient
	C - Thermal contact resistance
	D - Thermal diffusivity
	E - Specific heat at constant pressure
	F - Viscosity
	G - Emittance
	H - Reflectance
	I - Absorptance
	J - Transmittance
	K - Absorptance to emittance ratio
	L - Prandtl number
	N - Thermal linear expansion coefficient
	O - Thermal volumetric expansion coefficient
Physical State:	D - Doped
	E - Expanded
	F - Fibrous
	G - Gas
	L - Liquid
	M - Multiphase
	P - Powder
	S - Solid
Subject:	C - Calculated values + Theoretical
	D - Data
	E - Experimental + Theoretical
	G - General (Data + Experimental + Theoretical)
	M - Measured data + Experimental
	S - Survey, review, compendium, data collection, etc.
	T - Theoretical
Language:	C - Czech
	D - Dutch
	E - English
	F - French
	G - German
	I - Italian
	J - Japanese
	O - Other languages
	R - Russian
	S - Spanish
Temperature:	F - Full range (Low + Normal + High)
	L - Low (0 to 75 K) + Overlap into normal
	N - Normal (75 to 1273 K)
	H - High (1273 K and up) + Overlap into normal
	U - Undefined

TABLE III. CODE LETTER AND NUMBER DESIGNATIONS FOR CODING OF LITERATURE ON ELECTRONIC PROPERTIES

Specific Properties	Dopant	Physical State	Temperature
AS-absorption coefficient	1-group IA & IB	A-Amorphous	L-Low ≤ -198 C ≤ 75 K ≤ -324 F ≤ 136 R
DC-dielectric constant	2-group IIA & IIB	C-Superconductive	
DS-dielectric strength	3-group IIIA	D-Doped	
EB-energy band	4-group IVA	G-Gas	N-Normal ≤ 1000 C ≤ 1273 K ≤ 1832 F ≤ 2292 R or when unspecified
EF-effective mass	5-group VA	I-Ionized state (plasma)	
EG-energy gap	6-Group VIA	L-Liquid	
EH-electric hystersis	7-group VIIA & VIIIA	S-Solid	
EL-energy level	8-group IVB, VB, VIB, VIIB, & VIII	T-thin or thick film	
ER-electrical resistivity	9-group IIIB, Lanthanide Series, Actinide Series		H-High > 1000 C > 1273 K > 1832 F > 2292 R
HC-Hall coefficient	0-other or unspecified		
MH-magnetic hystersis			
MO-mobility			
MS-magnetic susceptibility			
RI-refractive index			
WF-work function			

General Properties	Abstract	Subject	Language
EP-electron emission properties	A-Coded from abstract, document to be acquired later	D-data	E-English
GP-magnetoelectric properties	B-Coded from abstract, document available	E-experimental	F-French
LP-luminescence properties	D-Coded from document	S-survey, review	G-German
MP-magnetomechanical properties		T-theory	O-Other
PP-photoelectronic properties			
TP-thermoelectric properties			R-Russian
ZP-piezoelectric properties			

TABLE IV. PROPERTY FILE SIZES

Thermophysical Properties	% of Total File	Electronic Properties	% of Total File
Thermal conductivity	22.0	Electrical resistivity	19.4
Specific heat	16.4	Dielectric constant	9.2
Thermal linear expansion	12.7	Absorption coefficient	6.8
Viscosity	12.5	Magnetic susceptibility	6.7
Reflectance	8.2	Magnetic hysteresis	5.8
Transmittance	6.5	Energy gap	5.7
Diffusion coefficient*	5.2	Luminescence properties	4.8
Surface tension*	4.5	Thermoelectric properties	4.7
Emittance	3.9	Mobility	4.5
Thermal diffusivity	2.6	Dielectric strength	4.4
Absorptance	2.0	Energy levels	4.4
Thermal volumetric expansion	1.7	Photoelectronic properties	3.6
Thermal contact resistance	0.7	Energy band structure	3.4
Accommodation coefficient	0.6	Hall coefficient	3.3
Prandtl number	0.3	Electron emission properties	2.3
Solar absorptance to emittance ratio	0.2	Refractive index	2.2
	100%	Magnetoelectric properties	2.1
		Effective mass	2.0
		Work function	1.8
		Magnetomechanical properties	1.4
		Electric hysteresis	0.8
		Piezoelectric properties	0.7
			100%

* These properties have not been monitored since mid-1970.

similar groups, selected preferably by their chemical composition. However, because of their inherent nature, certain substances do not lend themselves to a purely chemical classification and a more logical method has been adopted to classify them, instead, by their physical form and/or use and application. The present classification scheme has been used successfully over the years for the classification of the more than 70,000 different substances and materials, for which information is available in the TEPIAC file.

3. COMPUTERIZED INFORMATION STORAGE AND RETRIEVAL SYSTEM

The past sustaining efforts towards the completion of the software to achieve effective computerized storage and retrieval of bibliographic information on thermophysical properties have resulted in TEPIAC's possession of a completely mechanized and computerized system within the constraints of the CDC 6500 computer facility at Purdue University. TEPIAC now has a fully automated bibliographic search capability for thermophysical properties to respond to specific inquiries or to process standing requests for a continuing bibliographic service tailored to meet demands for specific technical profiles of individual engineers, scientists, corporations, laboratories, or governmental agencies.

The computer tapes from the former EPIC consisted of the following: (1) a Materials tape which contains the material names and the corresponding material numbers, (2) an Index tape which contains the material numbers and the respective document accession numbers, and (3) a Bibliographic tape which contains the bibliographies for the document accession numbers in the former EPIC system. All tapes have been converted for use with the CDC 6500 computer available at Purdue University. Furthermore, the former EPIC documentation file did not have a duplicate search capability, and a duplicate search file for the former EPIC documents has been created by the development of a computer program that recognizes word patterns for the document sources to the 49,300 references of the former EPIC.

The existing computer programs used in the documentation file for thermophysical properties have completely been modified for use in the documentation file for electronic properties.

4. RESEARCH LITERATURE RETRIEVAL GUIDE AND SUPPLEMENT

The information resulting from scientific documentation efforts on thermophysical properties is disseminated partly through the formal publication entitled "Thermophysical Properties Research Literature Retrieval Guide" and its supplement.

The Basic Edition of the Retrieval Guide which covers the publication years up to 1964 was published in 1967 and contains the resulting information from the first 33,700 research documents. Its full reference citation is as follows:

> Thermophysical Properties Research Literature Retrieval Guide, Touloukian, Y.S. (Editor), Gerritsen, J.K. (Technical Editor), and Moore, N.Y. (Coordinating Editor), Basic Edition, Books 1 to 3, Plenum Press, New York, 2936 pp., 1967.

Much of the manuscript of this 2936-page three-book volume was prepared by computer listings which were resulted from special computer programs. It provides a quick access to the world literature published from January 1920 (in some cases earlier) to June 1964 on thirteen thermophysical properties. It contains 139,305 codification entries on thirteen thermophysical properties of 45,116 materials, citing 33,700 references representing 26,562 authors and 3,600 scientific and technical journals and governmental and industrial report sources.

The information on thermophysical properties resulting from the research document accession numbers from 33,701 to 60,000 is contained in the Retrieval Guide Supplement I which was published in early October 1973. Its full reference citation is as follows:

> Thermophysical Properties Research Literature Retrieval Guide Supplement I (1964-1970), Touloukian, Y.S. (Editor), Gerritsen, J.K. (Technical Editor), and Shafer, W.H. (Managing Editor), Volumes 1 to 6, IFI/Plenum Data Corp., New York, 2225 pp., 1973.

This six-volume Retrieval Guide Supplement I contains 87,050 codification entries on sixteen thermophysical properties of 16,745 materials, citing 26,300 references published from mid-1964 to December 1970. An additional 9,000 synonyms and trade names are cross-referenced to assist the user in identifying the materials of interest.

Supplement I follows the same format of presentation as the Basic Edition. However, it has been restructured for improved user convenience in that a series of six Retrieval Guides have been designed for various materials classes. As a result, each user group can purchase, at a reasonable cost, selected volumes of specific interest, as well as the complete six-volume set. Each volume consists of the following four parts:

Part A. Materials Directory
Part B. Search Parameters
Part C. Bibliography
Part D. Author Index

Table V lists the titles and number of pages of the six volumes of the Retrieval Guide Supplement I.

Since the publication of the Retrieval Guide Supplement I, information on thermophysical properties has been accumulated from 13,400 additional research documents with accession numbers 60,001 to 73,400 and the total number of codification entries has been increased from 226,355 to 293,392. This information will be published in the Retrieval Guide Supplement II in the near future. Table VI shows the statistical data on thermophysical properties coverage of the world literature, listing the total number of materials in each material group, the total number of codification entries for each thermophysical property, and the grand totals in the computerized bibliographic information storage and retrieval system as of 31 December 1976.

The information on electronic properties resulting from scientific documentation efforts on the former EPIC documents with document accession numbers 1 to 42,000 has been published in the "Electronic Properties of Materials: A Guide to the Literature," Volumes 1 (1681 pp., 1965), 2 (1799 pp., 1967), and 3 (1917 pp., 1971). The accumulated information on electronic properties from 7300 former EPIC documents with accession numbers 42,001 to 49,300 and from the new EPIC/TEPIAC documents with accession numbers 49,301 to 66,809 will be published in the future Retrieval Guide.

TABLE V. THERMOPHYSICAL PROPERTIES RESEARCH LITERATURE RETRIEVAL GUIDE SUPPLEMENT I

(Covering the publication years 1964-1970)

		No. of Pages
Volume 1.	Elements and Inorganic Compounds	740
Volume 2.	Organic Compounds and Polymeric Materials	269
Volume 3.	Alloys, Intermetallic Compounds and Cermets	393
Volume 4.	Oxide Mixtures and Minerals	247
Volume 5.	Mixtures and Solutions	302
Volume 6.	Coatings, Systems, and Composites	274
	Total	2225

TABLE VI. STATISTICAL DATA ON THERMOPHYSICAL PROPERTIES COVERAGE OF THE WORLD LITERATURE*

Material Group	No. of Materials as of 31 Dec. 1976	Property	No. of Codification Entries as of Dec. 31, 1976
Elements and compounds	14,073	Thermal conductivity (including accommodation coefficient and thermal contact resistance)	65,596
Ferrous and nonferrous alloys	15,814	Specific heat	52,152
Mixtures	17,670	Viscosity	64,647
Systems, composites, etc.	4,324	Thermal radiative properties	38,534
Polymers, rubbers, etc.	3,047	Mass diffusivity (to 1972)	28,780
Refractories	1,977	Thermal diffusivity	5,683
Glasses	1,900	Prandtl number	965
Natural products	1,632	Coefficient of thermal expansion	21,035
Minerals	1,416	Others	16,000
Paints, slags, aggregates, cermets, etc.	7,276		
Grand Total	69,129	Grand Total	293,392

Number of Documents Coded for Retrieval 73,400
Number of Document Sources 7,600

* Coverage retrospective to the year 1920 or earlier.

SECTION III

DATA TABLES ACTIVITIES

1. DATA EXTRACTION AND COMPILATION

As a result of the systematic and comprehensive search of literature in the scientific documentation phase of this program described above, the original research documents of interest to TEPIAC are uncovered. These documents are procured and studied, from which the data are extracted, scrutinized, organized, converted to be in uniform units, and homogeneously plotted and tabulated in the form of "Tables of Original Data" which present all the available experimental data and information, as the first stage toward the preparation of internally consistent tables of critically evaluated "best data" referred to as "Tables of Recommended Reference Values." Subsequently, this information is reviewed and the organized data are given a final critical evaluation. At this second stage, the experimental data are analyzed, correlated, and synthesized, and the recommended values are generated. This two-stage data processing is found by TEPIAC to be the most logical approach lending itself to greater effectiveness in bringing to the user the results of this type of painstaking research in the shortest possible time.

The detailed procedures which TEPIAC follows in data compilation as well as in data analysis and synthesis are not necessarily a matter of established routines and do vary from property to property and from one group of materials to another. There are certain principles which must be followed, however, irrespective of the type of data or materials involved. For example: (a) the data should be extracted directly from their original sources to ensure freedom from errors of transcription; (b) the characterization and physical and chemical conditions of the test specimen should be specified as clearly as possible so as to fully identify the materials tested; (c) especially for solids, the source of the material, method of fabrication, thermal history, heat, mechanical, irradiative, and other treatments of the specimen and the measuring method and conditions should be noted; (d) if a comparative measurement method is used, the material used as comparative standard and its property values should be cited; (e) the accuracy and precision of the data reported should be separately denoted; (f) the complete reference to the original work should always be cited with the data; etc. Whenever some of the above criteria cannot be satisfied because of absence of necessary information in the original work, an attempt is made to contact the author, if possible. In the cases where data cannot be adequately evaluated by TEPIAC due to lack of required information, such data are appropriately "flagged".

In connection with its activities in data processing, TEPIAC has established, through experience, appropriate procedures of operational practice which lend to good organization of work, uniform recording and filing, and other procedures of "good housekeeping," thus assuring ready tractability of original records of processed data, which are permanent working records for reference at any time in the future. Every effort has been made and all necessary steps have been taken to ensure that the data tables production rate is the maximum possible consistent with TEPIAC's high professional standards.

The overall data tables activities to date cover eleven thermophysical properties and seven electronic, electrical, and optical properties. The eleven thermophysical properties on which data tables have been prepared are thermal conductivity, specific heat at constant pressure, emittance, reflectance, absorptance, transmittance, solar absorptance to hemispherical total emittance ratio, thermal diffusivity, viscosity, thermal linear expansion, and thermal volumetric expansion. The materials covered for thermophysical properties include metals and metal alloys, nonmetallic elements, graphites, compounds, ceramics, cermets, intermetallics, polymers, composites, glasses, applied coatings, systems, and other kinds of important materials.

The seven electronic, electrical, and optical properties on which data tables are being prepared so far are electrical resistivity, refractive index, absorption coefficient, thermoelectric power, Hall coefficient, mobility, and figure of merit. The materials covered so far are elements, alloys, compounds, and semiconductors.

Within each data tables project there are four major tasks: (a) data extraction and compilation, (b) data evaluation, analysis, synthesis, and generation of recommended reference values, (c) preparation of a text, which is a comprehensive state-of-the-art summary and critical review of the theories, estimation methods, and measurement techniques for the property, and (d) preparation of a manuscript for publication.

The statistical summary of accomplishments of the task on data extraction and compilation for all the data tables projects are presented in Table VII, which shows that in this 15-month contractual period 3,310 research documents have been processed for data extraction and 4,897 data sets have been compiled. These make a grand total of 32,084 research documents processed for data extraction, and TEPIAC has compiled a total of 78,653 data sets in its data file. It is important to note that data extraction and compilation is only one of the tasks and a small part of the total efforts. The activities in the other tasks are discussed later.

TABLE VII. STATISTICAL SUMMARY OF ACCOMPLISHMENTS OF DATA EXTRACTION AND COMPILATION

	Total as of 30 Sept. 1975	This Period	Total as of 31 Dec. 1976
No. of documents processed	32,084	3,310	35,394
No. of documents accepted as data sources	14,811	1,855	16,666
No. of materials compiled	10,028	198	10,226
No. of data sets compiled	78,653	4,897	83,550

In many of the research documents data are presented in graphs only. A Gerber Electronic Data Point Reader has been in operation to accurately read the data points off graphs. In this 15-month period data from 1,607 graphs were read with the Gerber Data Point Reader. Each graph normally presents more than one set of data. Whenever the graph is too small to give accurate readings, an attempt is made to contact the author for original data in tabular form.

The present Gerber Electronic Data Point Reader, however, is one of the earliest models of its kind. Although it is still useful and can make accurate reading of data points, its speed is not high enough and it cannot perform sophisticated functions. Consequently, a higher speed and more versatile electronic digitizer is needed for replacement. In this connection it is fortunate that Purdue University has supplied funds to develop an in-house digitizer-computer facility to be used by TEPIAC for high speed data processing. Most of the equipment has been received and installed, and is undergoing initial checkout.

2. DATA EVALUATION, CORRELATION, ANALYSIS, SYNTHESIS, AND GENERATION OF RECOMMENDED VALUES

Due to the difficulties in accurate measurement of properties of materials and in adequate characterization of test specimens, the available experimental data from the scientific and technical literature are in many cases conflicting, widely divergent, and subject to large uncertainty. Indiscriminate use of literature data for engineering design calculations without knowing their reliability is dangerous and may cause inefficiency or product failure, which at times can be disastrous. Consequently, only critically evaluated data should ever be used for design purposes.

It is therefore an imperative task to critically evaluate and analyze the available data, to give judgment on the reliability and accuracy of the data, and to generate recommended values. The procedure involves critical evaluation of the validity of the data and related information, resolution and reconciliation of disagreements in conflicting

data, correlation of data in terms of various controlling parameters, curve fitting with theoretical or empirical equations, comparison of results with theoretical predictions or with results derived from theoretical relationships or from generalized empirical correlations, etc. Besides critical evaluation and analysis of existing data, theoretical methods and semiempirical techniques are employed to fill data gaps and to synthesize fragmentary data so that the resulting recommended values are internally consistent and cover as wide a range of each of the controlling parameters as possible.

Considering the thermal conductivity data for example, in the critical evaluation of the validity and reliability of a particular set of experimental data, the temperature dependence of the data is examined and any unusual dependence or anomaly is carefully investigated. The experimental technique is reviewed to see whether the actual boundary conditions in the measurement agreed with those assumed in the theoretical model used to define the property. It is ascertained whether all the stray heat flows and losses were prevented or minimized and accounted for. Furthermore, the reduction of data is examined to see whether all the necessary corrections were appropriately applied, and the estimation of uncertainties is checked to ensure that all the possible sources of errors, particularly systematic errors, were considered by the authors. Since the primary factor contributing to unreliable and erroneous experimental results is the systematic error in the measurement, experimental data can be judged to be reliable only if all sources of systematic error have been eliminated or minimized and accounted for. Major sources of systematic error may include unsuitable experimental method, poor experimental technique, poor instrumentation and poor sensitivity of measuring devices, sensors, or circuits, specimen and/or thermocouple contaimination, unaccounted for stray heat flows, incorrect form factor, and, perhaps most important, the mismatch between actual experimental boundary conditions and those assumed in the theoretical model used to derive the value of thermal conductivity. These and other possible sources of errors are carefully considered in critical evaluation of experimental data. The uncertainty of a set of data depends, however, not only on the estimated error of the data but also on the adequacy of characterization of the material for which the data are reported.

Besides evaluating and analyzing individual data sets, correlation of data in terms of various controlling parameters is a valuable technique that is frequently used in data analysis. These parameters may include purity, composition, residual electrical resistivity or electrical resistivity ratio (if a metal), density or porosity, hardness, crystal axis orientation, degree of cold working, degree of heat treatment, etc. Applying the principle of corresponding states, reduced property values may be correlated with reduced temperature, pressure, and other reduced parameters.

Several properties of the same material can also be cross-correlated. For instance, thermal conductivity, specific heat, and density can be correlated with thermal diffusivity, and viscosity and specific heat of a gas can be correlated with thermal conductivity through the Chapman-Enskog theory or through the experimental data on the Prandtl number. For a fluid, the property of the saturated liquid can also be correlated with that of the saturated vapor.

In the years ahead, it is hoped that an increasingly larger portion of our total effort will be directed toward data analysis and synthesis along with data compilation. The former is a slow and painstaking task seldom fully appreciated by those who have not been involved with the generation or use of such information.

3. COMPUTERIZED NUMERICAL DATA STORAGE AND RETRIEVAL SYSTEM

Since its very inception, TEPIAC has recorded the numerical data and relevant information extracted from the open and report literature on specially designed forms and stored such data and information in three-ring notebooks housed in floor-to-ceiling bookshelves. With this manually operated hard-copy numerical data base, TEPIAC does not possess a computerized numerical data retrieval capability which is long overdue, though TEPIAC has possessed a computerized retrieval capability on bibliographic information. Furthermore, the storage and safekeeping of these numerous notebooks of valuable data files have always been a serious problem. It was therefore decided to convert the manually operated hard-copy data base to a computerized numerical data base and store all data on magnetic tapes.

In 1976 considerable effort has been devoted to the development of the computerized numerical data storage and retrieval system, and the planning of the optimum way for capturing the data in a universal mode that will find the broadest application and usefulness has been completed. A pilot experiment will be conducted early in 1977 prior to the initiation of major keyboarding effort required.

The new computerized numerical data system, when completed, will be able to perform at least the following functions:

1. Store and retrieve recommended reference data together with information on material identification and characterization and on data uncertainty.
2. Store and retrieve raw experimental data together with information on specimen specification and characterization and on measurement method and conditions.
3. Manipulate data for data analysis, correlation, curve fitting, derivation, etc.

4. Prepare tables, graphs, and list of references by computer for publication or for answering technical inquiries.
5. Be used for on-line computer search.

4. DATA TABLES PROJECTS

While our scientific documentation activities are being maintained on a fairly even level and operated on a current basis, the efforts on data tables activities are not being kept abreast with the world's generation of new data. Because of the immense amount of new research documents generated every year and because of the limited funding level, it is impossible at the present level of operation to extract and evaluate data from all the research documents, and consequently our data tables program, though among the most comprehensive of all known activities of its kind, is not quite adequate.

In order to partially remedy this situation and to achieve relatively effective and broad representation of the available data, the data extraction has been selective so as to include the more important and useful data in the data tables. Along with data extraction and compilation, parallel efforts are directed toward data evaluation, analysis and synthesis, generation of recommended values, writing of texts, and preparation of manuscripts for publication.

The following summaries serve to characterize each of the data tables projects, some of which were, however, not totally funded under this contract.

a. Thermal Conductivity

Thermal conductivity tables have been prepared for all kinds of important materials and the extraction of new data, critical evaluation, and generation of recommended values have always been continued. The tables prepared before 1969 have been published in Volumes 1, 2, and 3 of the Thermophysical Properties of Matter - The TPRC Data Series. Since the completion of the three volumes on thermal conductivity, efforts have been continued to extract and evaluate new data and to generate new recommended values.

In the general category of metallic elements and alloys, thermal conductivity tables have been prepared for elements, nonferrous binary alloys, nonferrous multiple alloys, ferrous alloys (carbon steels, cast irons, alloy steels), and intermetallic compounds and their mixtures. In the general category of nonmetallic solids, thermal conductivity tables have been prepared for elements, graphites, oxides and their mixtures, borides, bromides, carbides, chlorides, fluorides, nitrates, nitrides, phosphates, sulfates, sulfides, cermets, minerals and rocks, aggregate mixes, refractories, ceramics,

glasses, polymers, organic compounds, systems, natural substances and their derivatives (foods and biological materials), fabrics, yarns, hairs, composites, slags, scales, and residues. In the general category of nonmetallic liquids and gases, thermal conductivity tables have been prepared for elements, inorganic compounds, organic compounds, and binary, ternary, quaternary, and multicomponent mixtures. The tables for part of the material groups listed above are prepared under other sponsorships.

In the Basic Edition of the Thermophysical Properties Research Literature Retrieval Guide, which contains 33,700 references, there are 7329 references on thermal conductivity, i.e., 21.75%. The present rate of document input into TEPIAC Bibliographic Information Storage and Retrieval System for Thermophysical Properties is about 5000 per year, and the percentage for thermal conductivity remains approximately the same, as indicated by the relative file size (22.0%) for thermal conductivity shown in Table IV. There are, therefore, about 1100 new documents per year on thermal conductivity alone. It becomes an impossible task at the present level of operation to maintain current by extracting data from all data source documents. Consequently, data extraction has to be selective and a similar situation exists for most of the other projects.

b. Specific Heat

Specific heat tables prepared before 1969 have been published in Volumes 4, 5, and 6 of the TPRC Data Series. The effort on the specific heat of solids has been very modest since 1971, while the effort on fluids has been continued through the support from other sources.

In July 1976 a Supplement to Volume 6 (Specific Heat - Nonmetallic Liquids and Gases) of the TPRC Data Series was completed. This Supplement contains 169 pages and covers the specific heat data and literature on 103 inorganic compounds and 204 organic compounds. It is organized into four sections: (I) specific heat of fluids, (II) supplemental references, (III) bibliography, and (IV) index to substances. The completed manuscript has been sent to Plenum Publishing Corporation for printing.

In the general category of metallic elements and alloys, specific heat tables have been prepared for elements, nonferrous binary alloys, nonferrous multiple alloys, and ferrous alloys (carbon steels and alloy steels). In the general category of nonmetallic solids, specific heat tables have been prepared for elements, graphites, oxides and their mixtures, antimonides, arsenides, beryllides, borides, bromides, carbides, chlorides, fluorides, germanides, hydrides, iodides, nitrates, nitrides, nitrites, phosphides, selenides, silicides, sulfates, sulfides, tellurides, glasses, and cermets. In the general

category of nonmetallic liquids and gases, specific heat tables have been prepared for elements, inorganic compounds, organic compounds, and mixtures. The tables on fluids have been prepared at CINDAS' Kobe Affiliate in Japan.

For each of the fluids, tables of recommended values have been prepared for saturated liquid, saturated vapor, zero-pressure gas (ideal gas), and gas at 1 atm. The values for the specific heat of zero-pressure gas (gas in the ideal-gas state), C_p^0, are usually generated from statistical mechanical calculations using the latest spectroscopic and molecular data. These are generally very reliable and cover a wide range of temperature. However, the values for gas at 1 atm, C_p^1, which are determined mainly by calorimetry, are generally less reliable and cover only a limited range of temperature. Consequently, efforts have been made to improve the values of C_p^1 and to extend the range of temperature by calculating the difference $(C_p^1-C_p^0)$ theoretically using the Berthelot equation of state and/or the second and third virial coefficients. From the results of $(C_p^1-C_p^0)$ and the values of C_p^0, new values of C_p^1 are being generated.

The work on the specific heat of fluids at high pressures has also been in progress.

c. Thermal Radiative Properties (Emittance, Reflectance, Absorptance, Transmittance, and Solar Absorptance to Hemispherical Total Emittance Ratio)

The difficult problem of organizing the data on thermal radiative properties was solved several years ago when we established an excellent scheme for the designation and categorization of the subproperties. According to our scheme, by applying the proper geometric conditions (hemispherical, angular, normal) and wavelength conditions (total, integrated, spectral, solar) to the four prime properties (emittance, reflectance, absorptance, transmittance), there are altogether thirty-three subproperties into which data may be properly organized for any one material. The wavelength range covered is from 0.05 to 1000 μm, which encompasses the thermal portion of the spectrum, and special attention is given to solar spectrum conditions.

In the general category of metallic elements and alloys, tables have been prepared for elements, binary alloys, multiple alloys, and intermetallic compounds. In the general category of nonmetallic solids, tables have been prepared for various pigmented coatings, contact coatings, and conversion coatings.

In addition to data compilation, the data for many materials have been analyzed and "analyzed data graphs" have been prepared in parallel to give the user an evaluated overview of the available data and information and to recommend values under specific environmental conditions wherever possible.

Most of the tables prepared for this group of properties have been published in Volumes 7, 8, and 9 of the TPRC Data Series. This data tables project was supported from 1966 to 1972 by the National Aeronautics and Space Administration.

In 1975, a crash program supported by the tri-service on the thermal radiative properties of 27 selected aerospace materials was conducted. Over 1,700 sets of new data were extracted, evaluated, and analyzed. These most comprehensively compiled data together with the recommended values were published in 1976 in a hard-bound volume entitled "Thermophysical Properties of Selected Aerospace Materials. Part I: Thermal Radiative Properties," as discussed in more detail later in the section on state-of-the-art reports.

d. Thermal Diffusivity

Thermal diffusivity tables have been prepared for elements, nonferrous binary alloys, nonferrous multiple alloys, ferrous alloys (carbon steels and alloy steels), intermetallic compounds, graphites, oxides and their mixtures, arsenides, borides, bromides, carbides, chlorides, fluorides, nitrides, phosphides, silicides, sulfides, tellurides, cermets, refractories, glasses, composites, systems, minerals and rocks, organic compounds, polymers, foods, and biological materials. The tables prepared before May 1972 have been published in Volume 10 of the TPRC Data Series.

The part of the tables covering the elements deserves special mention. Experimental thermal diffusivity data are available in the world literature for only about 39 of the 105 elements. Since the available data mostly cover only a small temperature range, most of the recommended thermal diffusivity values were therefore first derived from our recommended values of thermal conductivity, selected values of specific heat, and selected values of density or calculated density values from thermal expansion data. These derived values were then compared with the critically evaluated experimental thermal diffusivity data, wherever available, to generate the final recommended values. Besides these 39 elements, provisional values are derived for 36 other elements for which no experimental data are available. Thus, recommended and provisional values have been generated for totally 75 elements. These values serve to increase substantially not only the number of materials but also the range of temperatures for which information on thermal diffusivity is available.

e. Viscosity

The work on viscosity tables of fluids from 1967 to 1971 had been done at CINDAS' European Branch in the Belgian Institute for High Pressure, Brussels, Belgium. In

1971 the activity at this European Branch was discontinued and the work has since been continued at CINDAS' Kobe Affiliate, Kobe, Japan. This work has partly been supported through other sources.

Viscosity tables have been prepared for elements, inorganic compounds, organic compounds, and binary, ternary, quaternary, and multicomponent mixtures. For each of the pure fluids, tables of recommended viscosity values have been prepared for saturated liquid, saturated vapor, and gas at 1 atm. For each of the mixtures, tables of smoothed viscosity values, experimental data, and derived Sutherland coefficients for semi-theoretical calculations have been prepared. The tables prepared before September 1974 have been published in Volume 11 of the TPRC Data Series.

The work on the viscosity of fluids at high pressures has been in full progress and there exists a possibility that a Supplement to Volume 11 may be released.

f. Thermal Expansion (Linear and Volumetric)

This data tables project includes both linear and volumetric thermal expansion and each of these covers both percent expansion and expansion coefficient.

In the general category of metallic elements and alloys, thermal expansion tables have been prepared for elements, nonferrous binary alloys, nonferrous multiple alloys, ferrous alloys (cast irons, carbon steels, alloy steels), and intermetallic compounds and their mixtures. In the general category of nonmetallic solids, thermal expansion tables are being prepared for elements, graphites, oxides and their mixtures, salts, arsenides, borides, bromides, carbides, chlorides, fluorides, iodides, nitrides, phosphides, selenides, silicides, sulfides, tellurides, ceramics, cermets, refractories, glasses, minerals and rocks, composites, laminates, systems, organic compounds, polymers, foams, and fibers.

The tables for metallic elements and alloys were published in February 1976 in Volume 12 of the TPRC Data Series while those for nonmetallic solids will be published in Volume 13.

The manuscript of Volume 13 was completed at the end of 1976. This volume is entitled "Thermal Expansion - Nonmetallic Solids" and contains 1800 pages. It presents 4990 sets of thermal expansion data on 11 nonmetallic elements, 23 groups of graphites, 61 simple oxides, 76 complex oxides, 48 salts, 127 nonoxide compounds, 5 groups of ceramics, 11 groups of cermets, 15 groups of glasses, 60 polymers, and 15 groups of composites, with a total of 815 different materials. It contains 101 references to text on the theory, estimation, and measurement of thermal expansion and 1112

references to data sources. Of the 452 materials and groups of materials covered, the data for 228 (i.e., 50.4%) have been critically evaluated, analyzed and synthesized, and recommended values have been generated and are presented in this volume together with the original experimental data. The tables, figures, references, and material index (totaling 1701 pages) of this manuscript are being photographed at the Purdue University Central Duplicating Service. The resulting negatives for these 1701 pages together with the front matter and text will soon be sent to Plenum Publishing Corporation at New York City for printing. This volume is expected to be available mid-1977.

g. Electrical Resistivity

This data tables project has initially covered the electrical resistivity of elements. Subsequently the electrical resistivity of alloys is also included. The electrical resistivity of the elements is important not only in its own right, but is also essential for the study of alloys and other materials and properties. For example, it is highly important to know the electrical resistivity of metals and alloys in order to evaluate or estimate the thermal conductivity of these materials.

A survey of the former EPIC documentation file of 49,300 documents has shown that there are about 4,000 documents on the electrical resistivity of some 88 elements. These documents and the new documents input into the documentation file since 1973 have been used for data extraction and compilation.

The work on the electrical resistivity of alkali elements (Group IA) and alkaline earth elements (Group IIA) has been completed and the results were released in two state-of-the-art reports, which will be discussed in more detail later. The work on other groups of elements and on alloys is in progress.

h. Optical Constants (Refractive Index and Absorption Coefficient)

The materials covered initially in the optical constants project were the alkali halides. This group was chosen because they are of great current interest and importance in that they are among the most promising laser window materials for high power lasers. Subsequently, this project was expanded to cover also alkaline earth halides and IIB-VIA compounds, since these materials are also of great current interest and importance to laser optics and technology. In the future this project will cover also IIIA-VA compounds and other important materials.

In the former EPIC file of 49,300 documents, there exist approximately 175 documents on the optical constants of alkali halides, 100 for alkaline earth halides, 1000

for IIB-VIA compounds and 950 for IIIA-VA compounds. Data compilation was started from these documents while other additional references were picked up along the way.

The work on the refractive index of 20 alkali halides had been completed and the compiled experimental data and recommended reference values on the refractive index and its wavelength and temperature derivatives were released in a technical report. Subsequently, the results were published in the Journal of Physical and Chemical Reference Data, Volume 5, No. 2, pp. 329-528, 1976.

The work on the refractive index of alkaline earth halides and on the absorption index of alkali halides and alkaline earth halides is well underway.

i. Thermoelectric Properties (Thermoelectric Power and Figure of Merit)

Thermoelectric properties are important for thermoelectric power generation, thermoelectric refrigeration, energy conversion, and many other applications. Materials selected initially for this project were a number of semiconductors. For these materials, data tables are being prepared for four properties: thermoelectric power, electrical resistivity, thermal conductivity, and figure of merit.

j. Hall Coefficient and Mobility

Data on the Hall coefficient and mobility of the elements are being compiled as a by-product of the project on the electrical resistivity of the elements.

In the data compilation phase of the project on the electrical resistivity of the elements, in each paper selected for data extraction, data on electrical resistivity, Hall coefficient, mobility, and thermoelectric power of the elements are all extracted and compiled. As a result, a considerable amount of data on the Hall coefficient, mobility, and thermoelectric power of the elements is being compiled. However, no data analysis is planned for these properties of the elements at the present time.

5. THE TPRC DATA SERIES

Synthesis of existing fragments of knowledge is as important as the so-called original observation. The availability of adequate standard reference data for properties of materials is essential to national progress, economy, and defense. To this end TEPIAC has contributed greatly through the generation and dissemination of data tables on the properties of materials.

The 13-volume "Thermophysical Properties of Matter - The TPRC Data Series" is the final formal outlet of all data tables activities on thermophysical properties

programs and brings together the most comprehensive and authoritative compilations of the available numerical data for thermophysical properties of materials. Recommended reference values resulting from critical evaluation, analysis, and synthesis of the available data are also included. This new TPRC Data Series has evolved from the old three-volume loose-leaf 11" x 17" size TPRC Data Book, which was disseminated by TPRC from 1960 to 1967 and is well known nationally, and, indeed, internationally. As of January 1967, the old TPRC Data Book contains 3322 data sheets, reporting 11,425 test specimens and citing 3424 references. It had been restructured into volumes by property and extensively updated, upgraded, and enlarged to become the new TPRC Data Series in 13 volumes.

The TPRC Data Series contains totally 16,627 pages, reporting 43,604 sets of data on 7414 materials, citing 12,258 references. A summary of the statistical data on all the thirteen volumes and the Supplement to Volume 6 is given in Table VIII.

One of the major improvements of the new TPRC Data Series over the old TPRC Data Book is that each volume of the TPRC Data Series contains also a text on the theory, estimation, and measurement of the property and an overall material index, in addition to the most comprehensive compilation of numerical data. The content of the text is described in the next subsection. The material index lists alphabetically all the materials contained in the volume and in the companion volumes on the same property by common name, trade name, and chemical composition together with their respective volume number and page number. It also cross-indexes commercial and scientific designations as well as synonyms. Thus, it enables the user to locate easily and quickly the needed data for any material contained in the volume or in the companion volumes.

The numerical data for each material (except for the pure fluids) are presented in a full-page graph and also tabulated in a data table, accompanied by a table of specifications supplying for every set of data a concise description of the specimen characterization as well as the method of measurement and test conditions. For the pure fluids of Volumes 3, 6, and 11, a brief critical discussion is given for every fluid in place of the tables of specifications and raw data, which are presented through a departure plot, since the data in these three volumes have been critically reviewed and recommended reference values are presented.

Table IX shows the structure, scope, and publication schedule of the 13-volume Thermophysical Properties of Matter - The TPRC Data Series. The first twelve volumes of the Series had been published by IFI/Plenum Data Corporation, New York, in the form of formal hard-bound volumes, $8\frac{1}{2}$" x 11" in size and the manuscript of Volume 13 was

TABLE VIII. SUMMARY OF STATISTICAL DATA ON THERMOPHYSICAL PROPERTIES OF MATTER - THE TPRC DATA SERIES

	No. of Pages	No. of Materials	No. of Data Sets	No. of References To Text	No. of References To Data Sources	No. of References Total
Volume 1. Thermal Conductivity - Metallic Elements and Alloys	1595	892	5539	433	1013	1446
Volume 2. Thermal Conductivity - Nonmetallic Solids	1302	812	4627	439	598	1037
Volume 3. Thermal Conductivity - Nonmetallic Liquids and Gases	707	170	1505	681	725	1406
Volume 4. Specific Heat - Metallic Elements and Alloys	830	322	1186	61	428	789
Volume 5. Specific Heat - Nonmetallic Solids	1737	550	1009	61	457	518
Volume 6. Specific Heat - Nonmetallic Liquids and Gases	383	56	863	70	595	665
Volume 7. Thermal Radiative Properties - Metallic Elements and Alloys	1644	242	5130	149	371	520
Volume 8. Thermal Radiative Properties - Nonmetallic Solids	1890	782	4971	121	455	576
Volume 9. Thermal Radiative Properties - Coatings	1569	1161	5269	180	295	475
Volume 10. Thermal Diffusivity	760	445	1733	253	315	568
Volume 11. Viscosity	801	188	1803	1218	377	1595
Volume 12. Thermal Expansion-Metallic Elements and Alloys	1440	672	4253	91	781	872
Volume 13. Thermal Expansion-Nonmetallic Solids	1800	815	4990	101	1112	1213
Volume 6 Supplement	169	307	726	0	878	878
Total	16627	7414	43604	3858	8400	12258

TABLE IX.

STRUCTURE, SCOPE, AND PUBLICATION SCHEDULE OF
THERMOPHYSICAL PROPERTIES OF MATTER - THE TPRC DATA SERIES*

	1970	1972	1973	1974	1975	1976
Volume 1. Thermal Conductivity - Metallic Elements and Alloys	1595					
Volume 2. Thermal Conductivity - Nonmetallic Solids	1302					
Volume 3. Thermal Conductivity - Nonmetallic Liquids and Gases	707					
Volume 4. Specific Heat - Metallic Elements and Alloys	830					
Volume 5. Specific Heat - Nonmetallic Solids	1737					
Volume 6. Specific Heat - Nonmetallic Liquids and Gases	383					
Volume 7. Thermal Radiative Properties - Metallic Elements and Alloys	1644					
Volume 8. Thermal Radiative Properties - Nonmetallic Solids		1890				
Volume 9. Thermal Radiative Properties - Coatings		1569				
Volume 10. Thermal Diffusivity			760			
Volume 11. Viscosity					801	
Volume 12. Thermal Expansion - Metallic Elements and Alloys					1440	
Volume 13. Thermal Expansion - Nonmetallic Solids						1800

* The figure given for each volume is the number of pages.

completed at the end of 1976. Table IX also reflects the substantial increase in scope of Volumes 8, 10, 11, 12, and 13, which contain 1890, 760, 801, 1440, and 1800 pages, respectively, instead of 880, 500, 400, 500, and 500 pages projected several years ago.

The continuing and systematic nature of this program makes the TPRC Data Series unique, quite distinctive from other data sources or handbooks, in that its coverage is constantly updated to maintain current and constantly upgraded to include more and more critically evaluated and recommended reference data. Furthermore, for those users who have need for the most up-to-date information, we will provide specific inquiry services or one may subscribe to the automatic data update plan tailored to meet a specific technical profile of an engineer, scientists, corporation, laboratory, or governmental agency. Thus, the user can always get the "last word" from the Data Series generator, TEPIAC/CINDAS.

The above-outlined procedure for data dissemination closely parallels the concept which has been followed for the dissemination of bibliographic information. In other words, we publish our major accomplishments in formal volumes through commercial channels while we directly disseminate up-to-date information to maintain our publications and audience on a current basis.

As the monumental 13-volume 16,600-page TPRC Data Series is completed, a new plan for the future data tables generation and publication has already been developed, in which an 80-volume CINDAS Handbooks of Material Properties will be published. Volumes in this new Handbook Series will primarily be application (material) oriented, in contrast to the discipline (property) oriented structure of the current Data Series. The preparation of the first several volumes of the new Handbook Series will be initiated in 1977.

6. STATE-OF-THE-ART REPORTS AND CRITICAL REVIEWS

We have prepared and published comprehensive state-of-the-art summaries and critical reviews as the texts on "Theory, Estimation, and Measurement" of the individual volumes in the TPRC Data Series, though we have not issued them separately as state-of-the-art reports in the sense commonly understood by this term. In this contractual period, the text of Volume 12 was published in the volume and that of Volume 13 was completed. The text of each volume is a comprehensive state-of-the-art summary and critical review of the theories and physics of the property considered in the volume, of the experimental methods and techniques for measuring the property, and of the

methods for estimating the property values when experimental data are not available. Besides imparting a comprehensive and up-to-date knowledge of the property to the user, such information also enables the user to properly interpret and fully utilize the compiled data presented in the volume and also enhances the usefulness of the data themselves. It also provides the user with a "better feel" for the reliability of the data.

Additionally, one formal report was published and three formal reports were completed and released in this contractual period as described below.

(1) "Thermophysical Properties of Selected Aerospace Materials. Part I: Thermal Radiative Properties," Thermophysical and Electronic Properties Information Analysis Center, CINDAS - Purdue University, 1058 pp., 1976.

This technical report was published in August 1976 as a hard-bound book. It contains the results of Task A of the Tri-Service Special Project on the thermophysical properties of selected aerospace materials of interest to the laser hardened materials development.

Each subproperty is treated with respect to both wavelength and temperature dependences whenever possible. In the compilation of experimental data, all available data covering from the photographic region of the spectrum up to 100 μm are included. The recommended values resulting from critical evaluation, analysis, and synthesis of the available data and information cover the wavelength range of present interest from visible region (below 1 μm) to the infrared of 15 μm, if possible. Furthermore, the recommended values as a function of temperature are given for four particularly useful wavelengths (whenever possible): 2.8 μm, 3.8 μm, 5.0 μm, and 10.6 μm.

(2) "Electrical Resistivity of Alkali Elements," Purdue University, CINDAS Report 40, 144 pp., 1976.

This technical report presents and discusses the available data and information on the electrical resistivity of alkali elements (lithium, sodium, potassium, rubidium, cesium, and francium) and contains recommended reference values generated from critical evaluation, analysis, and synthesis of the available data and information. The compiled data include all the experimental data available from the literature and cover the temperature dependence, pressure dependence, and magnetic flux density dependence. The temperature range covered by the compiled data is from cryogenic temperatures to above the critical temperature of the elements. The recommended values are given for both the total electrical resistivity and the intrinsic electrical resistivity. For most of the elements, the recommended values cover the temperature range from 1 K to 2000 K.

(3) "Thermophysical Properties of Selected Aerospace Materials. Part II: Five Thermophysical Properties of Seven Materials," Purdue University, CINDAS Report 41, 243 pp., 1976.

This technical report contains the results of Tasks B, C, and D of the Tri-Service Special Project on the thermophysical properties of selected aerospace materials of interest to the laser hardened materials development.

This report presents the most comprehensively compiled experimental data and information on five thermophysical properties of seven selected aerospace materials and the recommended values resulting from critical evaluation, analysis, and synthesis of the available data and information.

The five thermophysical properties are thermal conductivity, specific heat, heat of fusion, thermal linear expansion, and thermal diffusivity. The seven selected materials are aluminum alloy 2024, AISI 304 stainless steel, Pyroceram (Corning 9606), silicon nitride (Si_3N_4), boron fiber epoxy composite, glass fiber epoxy composite, and graphite fiber epoxy composite.

(4) "Electrical Resistivity of Alkaline Earth Elements," Purdue University, CINDAS Report 42, 92 pp., 1976.

This technical report presents and discusses the available data and information on the electrical resistivity of alkaline earth elements (beryllium, magnesium, calcium, strontium, barium, and radium) and contains recommended reference values generated from critical evaluation, analysis, and synthesis of the available data and information. The compiled data include all the experimental data available from the literature. The temperature range covered by the compiled data is from cryogenic temperatures to above the melting temperature of the elements. The recommended values are given for both the total electrical resistivity and the intrinsic electrical resistivity. For most of the elements, the recommended values cover the temperature range from 1 K to 1000 K.

SECTION IV

INQUIRY SERVICES

TEPIAC's day-by-day contributions in inquiry services to individual users have been primarily in the nature of specialized advisory and technical consulting, data recommendation and prediction, and special bibliographic and data searches. During this 15-month contractual period 603 inquiries have been responded, of which 539 came from 40 states and the District of Columbia and 64 from17 foreign countries. It is noted also that 103 of the 603 inquiries came from government agencies, 153 from academic institutions, and 347 from industrial organizations. A list of organizations in the United States served by TEPIAC is given in the Appendix.

Detailed statistical summary of inquiry responses for this contractual period is given in Table X. In this table detailed distributions of inquiries among different types and among various sources are given. Table XI gives a breakdown on the geographical distribution of inquiry responses.

TABLE X. STATISTICAL SUMMARY OF INQUIRY RESPONSES
(For the period 1 October 1975 to 31 December 1976)

	Information Request	Publication Request	Technical Question*	Bibliographic Search	TOTAL
DOMESTIC					
Government	27	11	38	6	82
Industry	81	54	148	49	332
University	31	18	54	22	125
Subtotal	139	83	240	77	539
FOREIGN					
Government	7	4	9	1	21
Industry	9	3	3	0	15
University	5	3	19	1	28
Subtotal	21	10	31	2	64
TOTAL	160	93	271	79	603

* Including data analysis and technical review.

TABLE XI. GEOGRAPHICAL DISTRIBUTION OF INQUIRY RESPONSES

(For the period 1 October 1975 to 31 December 1976)

	No. of Inquiries
Alabama	6
California	91
Colorado	7
Connecticut	13
Delaware	4
District of Columbia	21
Florida	3
Georgia	2
Idaho	4
Illinois	27
Indiana	49
Iowa	1
Kansas	2
Kentucky	1
Louisiana	1
Maine	2
Maryland	21
Massachusetts	21
Michigan	21
Minnesota	9
Mississippi	1
Missouri	8
Montana	1
Nebraska	1
New Jersey	16
New Hampshire	1
New Mexico	16
New York	71
North Carolina	3
Ohio	27
Oklahoma	1
Oregon	4
Pennsylvania	32
Rhode Island	1
Tennessee	9
Texas	13
Utah	5
Virginia	8
Washington	12
West Virginia	2
Wisconsin	1
	539
Foreign Countries	64
TOTAL	603

In accordance with a DoD directive to institute a system of charges for inquiry services, TEPIAC developed a price schedule for individual inquiry services and a procedure for prepaid annual subscription and standing order which eliminates the necessity for processing of requisition for each inquiry and enables each individual to call or write directly. The charge for a technical inquiry is based on the professional effort involved in response to the inquiry and therefore does very considerably depending on the complexity of the question, the engineering time required for an authoritative response, and the associated expenses. Consequently, special price quotations are given on technical consulting, data analysis, recommendation, and prediction, etc. However, for a bibliographic search, the charge is uniform and nominal and is set at $35.00 for a single search. A single bibliographic search is defined as a search for a maximum of five different properties of one material. Upon request, the resulting references are sent to the requester in the form of standard microfiche or hard copy. The price is $1.50 per microfiche and $0.35 per hard copy page.

After 1970, the number of inquiries has decreased significantly. It may be partly due to the DoD policy of charges for services and partly due to the fact that as our major publications such as the TPRC Data Series, Retrieval Guide and Supplement, and other outputs are effectively disseminated to the scientific and technical community through commercial publishers, the users are more and more able to find the needed data and information from our publications, and the necessity to contact TEPIAC directly for information becomes less. However, due to our successful promotion efforts in recent years, a larger number of scientists and engineers are becoming increasingly aware of TEPIAC's activities, thus reflecting an upturn and a continuing small increase in inquiries in recent years since 1973.

In recent years it has been noted that, besides making important contributions to the research and development programs of government agencies and defense contractors for the Department of Defense, TEPIAC has contributed very significantly to the national energy programs. Increasing number of inquiries have come from workers in the research and development programs of nuclear breeder reactors, coal gasification, geothermal energy, fossil fuel exploration, solar energy, etc. Through many telephone dialogues with these users, we have learned that TEPIAC's publications are very popular also among workers in these fields.

Since most users contacted TEPIAC for data and information via the telephone, TEPIAC has installed a national WATS line to make easier for all users to call TEPIAC toll free. TEPIAC has attempted a number of innovations in getting the word out and the WATS line is one of the contributions to establish a better and easier communication.

TABLE XII. INTEREST PROFILE OF TECHNICAL INQUIRIES

A. Properties (listed in the order of interest)

1.	Thermal Conductivity	26.0%	13.	Thermal Volumetric Expansion	0.6%
2.	Specific Heat	16.0%	14.	Dielectric Strength	0.5%
3.	Thermal Linear Expansion	15.0%	15.	Mobility	0.4%
4.	Electrical Resistivity	9.0%	16.	Work Function	0.3%
5.	Viscosity	7.0%	17.	Absorption Coefficient	0.2%
6.	Thermal Diffusivity	6.0%	18.	Energy Gap	0.2%
7.	Emittance	5.0%	19.	Energy Bands	0.2%
8.	Refractive Index	4.0%	20.	Energy Levels	0.2%
9.	Reflectance	2.0%	21.	Thermoelectric Properties	0.1%
10.	Absorptance	2.0%	22.	Thermal Contact Resistance	0.1%
11.	Transmittance	2.0%	23.	Dielectric Constant	0.1%
12.	Magnetic Susceptibility	1.0%	24.	Misc. (10 electronic + 3 thermo.)	2.1%

B. Materials (listed in the order of interest)

1.	Inorganic Compounds	25.0%	9.	Minerals	4.0%
2.	Elements	18.0%	10.	Composites and Systems	1.5%
3.	Non Ferrous Alloys	14.0%	11.	Coatings	0.9%
4.	Intermetallics	12.0%	12.	Hydrocarbons*	0.9%
5.	Ferrous Alloys	6.0%	13.	Solutions and Mixtures	0.7%
6.	Glasses, Refractories, etc.	5.0%	14.	Cermets	0.6%
7.	Polymers	4.5%	15.	Foods	0.5%
8.	Organic Compounds*	4.2%	16.	Misc.	2.2%

* Hydrocarbons refer to the less complex compounds such as butene (C_4H_8), decene ($C_{10}H_{20}$), etc.. Organic compounds include all the other more complex compounds.

It would be interesting and informative to note the properties and materials the information on which is most frequently requested by the inquirers. Therefore, a study of the interest profile of the technical inquiries was made, based upon the technical inquiries responded from July to December 1973 and from January to June 1975, which were randomly selected for sampling. The findings are shown in Table XII. It is observed from Table XII that over 65% of the inquiries were on the top four of the 36 properties and top four of the material groups listed.

SECTION V

CURRENT AWARENESS AND PROMOTION EFFORTS

The "Thermophysics and Electronics Newsletter" has been issued bimonthly since January 1972 to a circulation list of TEPIAC users and potential users as a means of keeping them abreast of significant developments and coming events, the availability of new information and publications, the initiation of new R & D programs, and of the availability of products and services from TEPIAC. The number of names in the circulation list has been increasing slowly and reached 3,900. In this contractual period eight issues of the Newsletter have been released with a total of 31200 copies distributed.

In this contractual period, many copies of a four-page flier entitled "Thermophysical and Electronic Properties Information Analysis Center [TEPIAC]: A DoD Information Analysis Center," which were printed in July 1974, have continued to be distributed. This flier gives information on TEPIAC's background and activities, current scope of coverage, and prices and payment options for inquiry services.

In this period, TEPIAC staff participated in seven conferences and meetings. A list of the seven conferences and meetings is given in Table XIII.

TEPIAC has maintained periodic contacts with a number of national and international experts in the field of thermophysics and thermophysical and electronic properties and has developed cooperative working arrangements with a number of national and international laboratories and institutions engaged in thermophysical and/or electronic properties research for the exchange of ideas, technical information, and research results. During this period, seven foreign scientists from four countries visited TEPIAC to become better acquainted with our operations, methods and procedures, and programs. One scientist from Japan chose to stay at TEPIAC for a period of six months.

As part of the continuing effort to bring about improved awareness of the need and value of using evaluated reference data vs. data directly taken from the open literature, the filming of a 25-minute documentary film entitled "The Anatomy of Data" has been initiated and completed. This film is for the promotion of the concept and mission of the Information Analysis Centers in general and of the data analysis and synthesis activities of TEPIAC/CINDAS in particular. It points out and stresses the serious discord that exists among the numerical data of science and technology as reported in the open research literature. Through on-location interviews with prominent scientists

TABLE XIII. CONFERENCES AND MEETINGS PARTICIPATED BY TEPIAC STAFF MEMBERS IN THE PERIOD 1 OCTOBER 1975 TO 31 DECEMBER 1976

Name	Location	Date
Conference of the Technology and Management Advisory Service, American Defense Preparedness Association	Arlington, VA	Oct. 19-24, 1975
Sixth North American Thermal Analysis Society Conference	Princeton, NJ	June 23, 1976
Fifth International CODATA Conference	Boulder, CO	June 28-July 1, 1976
Annual Meeting of the Indiana Chapter of the American Society for Information Sciences	Bloomington, IN	April 13, 1976
Symposium on Vistas in Chemical Thermodynamics	Gaithersburg, MD	July 23, 1976
TRIS-On-Line Workshop	Evanston, IL	Sept. 30, 1976
Air Force Thermophysics Research Program Review Meeting	Wright-Patterson AFB, OH	Dec. 3, 1976

highly knowledgeable in this field, and using examples drawn from the files of CINDAS, the film illustrates the serious pitfalls an engineer or scientist may fall into unless he uses critically evaluated data prepared by such national centers as CINDAS. The role and usefulness of data synthesis is also stressed and demonstrated. This film is believed to be the only one available on this increasingly important subject and is a must viewing for engineers and scientists in industry and Federal research and development organizations and laboratories.

In addition, the plan for the development of an enlarged and computerized viable mailing list for TEPIAC is being implemented. A simple profile code is given to each name on the mailing list so that the computer can generate selective mailing lists from a master file. The new list will therefore not only cover a greater percentage of TEPIAC's total audience, but will also allow the isolation of selected portions of that audience for specialized mailings, which will increase the effectiveness of the mailing and save much money in dissemination costs.

SECTION VI

OTHER MAJOR PUBLICATIONS NOT UNDER THIS CONTRACT BUT IN DIRECT SUPPORT OF THIS PROGRAM

In the following are described some major technical products which are sponsored by sources other than DSA but are in direct support of this program.

1. NATIONAL STANDARD REFERENCE DATA SERIES

As a component of the National Standard Reference Data System - National Bureau of Standards (NSRDS-NBS) since 1964, TPRC/CINDAS has assumed its responsibility for the generation of Standard Reference Data on the thermophysical properties of substances and materials to meet the national needs. As a result, TPRC/CINDAS generates a series of reports giving recommended reference values for thermophysical properties of well-characterized substances, materials, or systems. While all numerical data find their way in the TPRC Data Series, these research reports discuss in detail the considerations involved in arriving at the recommended reference values with a full assessment of the experimental data and theoretical guidelines on which the critical evaluation, analysis, and synthesis are based. The reports are normally released by TPRC/CINDAS first in the form of a "preliminary report" and distributed internationally to a large number of experts for review and criticism. The formal reports are then published under NSRDS auspices and released in the National Standard Reference Data Series. Starting January 1972 the primary outputs of the NSRDS programs are published in the Journal of Physical and Chemical Reference Data, which is published by the American Chemical Society and the American Institute of Physics for the National Bureau of Standards.

TPRC/CINDAS' publications in this series are the following:

(1) "Thermal Conductivity of Selected Materials," R. W. Powell, C. Y. Ho, and P. E. Liley, National Standard Reference Data Series - National Bureau of Standards NSRDS-NBS 8, 1-168, 1966.

The work presented in this report consists of the critical evaluation, analysis, and synthesis of the available thermal conductivity data and the generation of recommended values for eleven metals and nine nonmetals mainly for the solid state, on seven fluids for both the fluid and gaseous states and on two for the liquid state only. These 29 substances and materials are: the metals aluminum, copper, gold, Armco iron, iron, manganin, mercury, platinum platinum (60%) - rhodium (40%) alloy, silver, tungsten; the nonmetallic solids aluminum oxide, beryllium oxide, Corning code 7740 glass, diamond, magnesium oxide, Pyroceram brand glass-ceramic code 9606, quartz, thorium dioxide, titanium dioxide; the fluids argon, carbon tetrachloride, diphenyl, helium, nitrogen, m-terphenyl, p-terphenyl, toluene, and water.

The materials studied were selected primarily for their potential applicability as reference standards.

(2) "Thermal Conductivity of Selected Materials, Part 2," C. Y. Ho, R. W. Powell, and P. E. Liley, National Standard Reference Data Series - National Bureau of Standards NSRDS-NBS 16, 1-146, 1968.

The work presented in this report comprises the critical evaluation, analysis, and synthesis of the available thermal conductivity data and the generation of recommended values for twelve metallic elements, mainly for the solid state, for a range of graphites, and for three fluids in the gaseous state. These are cadmium, chromium, lead, magnesium, molybdenum, nickel, niobium, tantalum, tin, titanium, zinc, zirconium, Acheson graphite, ATJ graphite, pyrolytic graphite, 875S graphite, 890S graphite, acetone, ammonia, and methane. For each of the materials recommended values are given over a wide range of temperature.

(3) "Thermal Conductivity of the Elements," C. Y. Ho, R. W. Powell, and P. E. Liley, J. Phys. Chem. Ref. Data, 1(2), 279-421, 1972.

This is the abridged version of a comprehensive volume on the thermal conductivity of the elements. It contains recommended reference values resulting from critical evaluation, analysis, and synthesis of all the available data. It also gives estimated values for those elements for which no thermal conductivity data are available. Thus, the work provides recommended or estimated thermal conductivity values for all the elements over the full temperature ranges where experimental data are available or reliable extrapolations or estimations can be made. The results on each element are presented in both graphical and tabular forms. Summary graphs arranged by group in the periodic table are also given.

(4) "Thermal Conductivity of the Elements: A Comprehensive Review," C. Y. Ho, R. W. Powell, and P. E. Liley, J. Phys. Chem. Ref. Data, 3 (Supplement 1), 796 pp., 1974.

This is the comprehensive volume on the thermal conductivity of the elements, the abridged version of which is item 3 listed above. In addition to the presentation of recommended reference data, this volume presents the original data, specimen characterization, and measurement information for the 5200 sets of raw data extracted from the primary literature. It contains also a detailed discussion for every element, reviewing the individual pieces of available data and information, and describing the considerations involved in arriving at the final assessment and recommendation and the theoretical guidelines or semiempirical correlations on which the data analysis and synthesis are based. The complete bibliographic citations for the 1658 references are also included.

(5) "Thermal Conductivity of Ten Selected Binary Alloy Systems," C. Y. Ho, M. W. Ackerman, K. Y. Wu, S. G. Oh, and T. N. Havill, CINDAS-TPRC Report 30, 230 pp., 1975. [To be published in the Journal of Physical and Chemical Reference Data]

This work presents and discusses the available data and information on the thermal conductivity of ten selected binary alloy systems and contains the recommended reference values (or provisional values) resulting from critical evaluation, analysis, and synthesis of the available data and information. The ten binary alloy systems are the systems of aluminum-copper, aluminum-magnesium, copper-gold, copper-nickel, copper-palladium, copper-zinc, gold-palladium, gold-silver, iron-nickel, and silver-palladium. The recommended (or provisional) values given include the total thermal conductivity, electronic thermal conductivity, and lattice

thermal conductivity. The values for each of the alloy systems except two are given for 25 alloy compositions: 0.5, 1, 3, 5, 10(5)95, 97, 99, and 99.5%. For most of the alloy compositions, the values cover the temperature range from cryogenic temperature to the solidus point or 1200 K. In addition, reliable methods for the estimation of the electronic and lattice thermal conductivities of alloys have been developed in this work.

2. MASTERS THESES IN THE PURE AND APPLIED SCIENCES

This annual publication was first conceived, published, and disseminated by TPRC in 1957, starting its coverage of masters theses with the academic year 1955. Beginning with Volume XIII, 1969, the printing and dissemination phases of the activity was transferred to the University Microfilms/Xerox of Ann Arbor, Michigan with the thought that such an arrangement would be more beneficial to the academic and general scientific and technical community. After five years of this joint undertaking it was concluded that the interest of all concerned could be better served if the printing and distribution of the volume would be handled by a well known publisher. Consequently, effective with Volume XVIII, 1974, this publication is disseminated on a worldwide basis by the Plenum Publishing Corporation in New York. All back issues can also be ordered from Plenum. Masters theses from Canadian universities will also be covered starting with Volume XVIII, which includes 1,400 thesis titles from 28 Canadian universities.

A brief statistical summary of coverage of this publication is given in Table XIV. Table XV shows a complete list of academic disciplines covered in the publication.

3. THERMOPHYSICAL PROPERTIES OF HIGH TEMPERATURE SOLID MATERIALS

"Thermophysical Properties of High Temperature Solid Materials," Y. S. Touloukian (Editor), Vol. 1 to 6, MacMillan Company, New York, 8549 pp., 1967.

This major encyclopedic reference work consists of 6 volumes comprising 9 books (Volumes 2, 4, and 6 consist of 2 books each) with a total of 8549 pages reporting data from 2447 references for 14,381 specimens in 1375 material groups. This work is available from the MacMillan Company as individual volumes as well as a complete set. The general contents of the respective volumes are as follows:

Volume 1.	Elements
Volume 2.	Nonferrous Alloys
Part I.	Nonferrous Binary Alloys
Part II.	Nonferrous Multiple Alloys
Volume 3.	Ferrous Alloys

TABLE XIV. STATISTICAL SUMMARY OF COVERAGE OF "MASTERS THESES IN THE PURE AND APPLIED SCIENCES"

Volume No.	Publication Date	Thesis Year	No. of Contributing Institutions	No. of Thesis Titles Reported
I	Oct. 1957			
Part I		1955	93	1,002
Part II		1956	93	1,027
II	Aug. 1958	1957	154	1,727
III[a]	Oct. 1959	1958	139	3,736
IV	Dec. 1960	1959	162	4,984
V	Dec. 1961	1960	183	5,708
VI	Aug. 1966	1961	186	5,911
VII	Aug. 1966	1962	186	6,321
VIII	Aug. 1966	1963	175	6,505
IX	Jan. 1968	1964	174	6,940
X	Jan. 1968	1965	170	7,310
XI	Jan. 1968	1966	173	7,099
XII	July 1968	1967	167	6,909
XIII	July 1969	1968	174	7,802
XIV	Jan. 1971	1969	175	7,160
XV	July 1971	1970	183	7,413
XVI	July 1972	1971	182	7,170
XVII	July 1973	1972	250	8,513
XVIII[b]	Dec. 1974	1973	251	10,381
XIX	Dec. 1975	1974	229	10,045
XX	Dec. 1976	1975	267	10,374

[a] Part II of Volume III includes doctoral dissertations for 1956-57 academic year, citing 2846 titles from 103 universities.

[b] Effective with Volume XVIII, the coverage was extended to include Canadian Universities.

TABLE XV. ACADEMIC DISCIPLINES COVERED BY THE "MASTERS THESES IN THE PURE AND APPLIED SCIENCES"*

1. Aerospace Engineering
2. Agricultural Economics, Sciences and Engineering
3. Architectural Engineering and Urban Planning
4. Astronomy
5. Astrophysics
6. Ceramic Engineering
7. Chemical Engineering
8. Chemistry and Biochemistry
9. Civil Engineering
10. Communications Engineering and Computer Science
11. Cryogenic Engineering
12. Electrical Engineering
13. Engineering Mechanics
14. Engineering Physics
15. Engineering Science
16. Fuels, Combustion and Air Pollution
17. General and Environmental Engineering
18. Geochemistry and Soil Science
19. Geological Sciences and Geophysical Engineering
20. Geology
21. Geophysics
22. Industrial Engineering and Operations Research
23. Irrigation Engineering
24. Marine and Ocean Engineering
25. Materials Science and Engineering
26. Mechanical Engineering and Bioengineering
27. Metallurgy
28. Meteorology and Atmospheric Sciences
29. Mineralogy and Petrology
30. Mining and Metallurgical Engineering
31. Missile and Space Systems Engineering
32. Nuclear Engineering
33. Nuclear Physics
34. Nuclear Science
35. Oceanography and Marine Science
36. Petroleum and Natural Gas Engineering
37. Photogrammetric and Geodetic Engineering
38. Physics and Biophysics
39. Plastics Engineering
40. Wood Technology, Forestry and Forest Science
41. Reactor Science
42. Sanitary Engineering and Water Pollution
43. Textile Technology
44. Transportation Engineering
45. Without Specification of School or Department

* Mathematical and most life sciences have been excluded on a purely arbitrary basis, simply to limit the scope of the work.

Volume 4. Oxides and Their Solutions and Mixtures
Part I. Simple Oxygen Compounds and Their Mixtures
Part II. Solutions and Their Mixtures of Simple Oxygen Compounds, Including Glasses and Ceramic Materials

Volume 5. Nonoxides and Their Solutions and Mixtures, Including Miscellaneous Ceramic Materials

Volume 6. Intermetallics, Cermets, Polymers, and Composite Systems
Part I. Intermetallics
Part II. Cermets, Polymers, and Composite Systems

The twelve specific properties covered in each volume are: density, melting point, heat of fusion, heat of vaporization, heat of sublimations, electrical resistivity, specific heat at constant pressure, thermal conductivity, thermal diffusivity, thermal linear expansion, thermal radiative properties (absorptance, emittance, reflectance, and transmittance), and vapor pressure.

Generally, only materials with melting points above 800 K (approximately 1000 F) are included, except for materials within the categories of polymers, plastics, and composites. A detailed discussion of the material classification scheme is given at the beginning of each volume and a comprehensive Materials Index for the entire work is included at the end of each volume. This work was sponsored by the Air Force Materials Laboratory of the U. S. Air Force Systems Command at Wright-Patterson Air Force Base, Ohio. This work supercedes an earlier compilation (1960), by the Armour Research Foundation, entitled "Handbook of Thermophysical Properties of Solid Materials" published first as WADC TR 58-476 and as a hard bound set by the MacMillan Company.

SECTION VII

CONCLUSIONS AND FUTURE PLANNING

This Final Report has covered all phases of activities and tasks of the Thermophysical and Electronic Properties Information Analysis Center in the contractual period 1 October 1975 to 31 December 1976 and has contained details of all technical work accomplished and information gained in performance of the contract. TEPIAC has maintained a comprehensive and up-to-date national data base on thermophysical and electronic properties of materials, and has disseminated the data and information resulting from this program to the general users at large through formal publications and other technical products and at the same time has provided the data and information directly to individual users through technical and bibliographic inquiry services. It is believed that the accomplishments of TEPIAC have far exceeded the requirements of the contract.

Some of the data tables projects described herein were not funded or not totally funded under this contract, and the supports from other sources have therefore benefited this contract greatly. In fact, the present accomplishments would not have been possible without the additional supports from other sources, which include principally the Office of Standard Reference Data - National Bureau of Standards, the National Science Foundation, the Air Force Office of Scientific Research, and the American Iron and Steel Institute.

The objective of TEPIAC operations is to increase the productivity of scientists, engineers, and technicians engaged in scientific and engineering programs for the Department of Defense by maintaining a comprehensive and up-to-date national base for use by the entire DOD community and by providing authoritative information and data analysis services. This objective has thus been accomplished very successfully, as evidenced by the accomplishments discussed throughout this report.

To the extent that TEPIAC's activities constitute a continuing program, the planning of its activities has been geared to both short range as well as long range goals, thus leading to effective utilization of both intellectual and fiscal resources.

As the monumental 13-volume 16,600-page TPRC Data Series is completed, a new plan for the future data tables generation and publication has been developed. In this future plan it is proposed to publish an 80-volume CINDAS Handbooks of Material Properties within a time frame of about ten years. Volumes in this new Handbook Series will primarily be application (material) oriented, in contrast to the discipline (property) oriented structure of the current Data Series. In other words, each volume will contain

data on all the important physical properties of a small group of materials. In presenting the property data, all possible steps will be taken to reduce the bulk of the presentation by limiting the reporting to essential elements of information without sacrificing information essential for scientific and technical usage of the data reported.

APPENDIX

APPENDIX

ORGANIZATIONS SERVED BY TEPIAC*

(In the Period 1 October 1975 to 31 December 1976)

A. B. Chance Company
Centralia, MO

Action Research
Acton, MA

Actron, Inc.
Monrovia, CA

Acurex Corporation
Mountain View, CA

Aerojet Electrosystems
Azusa, CA

Aerojet Nuclear Co.
Idaho Fall, ID

Aerospace Corp.
Los Angeles, CA

Air Force Materials Laboratory
Wright-Patterson Air Force Base, OH

Air Force Office of Scientific Research
Bolling Air Force Base, DC

Air Force Rocket Propulsion Laboratory
Edwards Air Force Base, CA

Air Force Weapons Laboratory
Kirkland Air Force Base, NM

Air Products and Chemical Co.
Allensburg, PA

AIRCO, Inc.
Murray Hill, NJ

Aluminum Company of America
Alcoa Center, PA

American Home Foods, Inc.
LaPorte, IN

American Iron and Steel Institute
Washington, DC

Amoco Chemical Co.
Naperville, IL

Anaconda Brass Company
Waterbury, CT

Anaconda Company
Marion, IN

Anamet Lab, Inc.
San Carlos, CA

Argonne National Laboratories
Argonne, IL

Army Materials and Mechanics Research Center
Watertown, MA

Arthur D. Little, Inc.
Cambridge, MA

Ashland Chemical Co.
Columbus, OH

Atlantic Research Center
Alexandria, VA

Atlantic Richfield Hartford Co.
Richland, WA

Atomic Energy Documentation Service, Inc.
Larchmont, NY

Atomic International
Canoga Park, CA

Autonetics, Inc.
Anaheim, CA

Baker and Taylor Co.
Somerville, NJ

Ball Corp.
Muncie, IN

* Only organizations within the United States are listed.

Barber Colman Company
Loves Park, IL

Battelle Columbus Laboratories
Columbus, OH

Battelle-Northwest
Richland, WA

Bechtal Power Company
San Francisco, CA

Bell Laboratories
Murray Hill, NJ

Bendix Corp.
Dayton, OH

Boeing Company
Seattle, WA

Boeing Computer Services
Richland, WA

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Brigham Young University
Provo, UT

Brookhaven National Laboratories
Upton, NY

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Department of Transportation
Washington, DC

Desota, Inc.
Des Plaines, IL

Dow Chemical Company
Midland, MI

DuPont Chemicals
Wilmington, DE

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Wilmington, DE

Eastman Kodak Co.
Rochester, NY

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Exxon Research Center
Linden, NJ

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Rockville, MD

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National Materials Advisory Board/NAS
Washington, DC

National Metallizing Div.
Cranbury, NJ

National Science Foundation
Washington, DC

Naval Material Command
Washington, DC

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THERMOPHYSICAL AND ELECTRONIC PROPERTIES INFORMATION ANALYSIS CENTER (TEPIAC) - A Continuing Systematic Program on Tables of Thermophysical and Electronic Properties of Materials
C. Y. Ho, Center for Information and Numerical Data Analysis and Synthesis, Purdue University, West Lafayette, Indiana 47906

Technical Report AMMRC CTR 77-7, February 1977,
55 pp-tables, Contract DSA900-76-C-0860
D/A Project 1T162105AH84, AMCMS Code 612105.11.H8400
Final Report, 1 October 1975 to 31 December 1976

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The activities and accomplishments of the Thermophysical and Electronic Properties Information Analysis Center (TEPIAC) reported include literature search, acquisition, and input of source information; document review and codification and substance classification; operation of a computerized information storage and retrieval system; preparation and publication of the Thermophysical Properties Research Literature Retrieval Guide Supplement; data extraction and compilation; data evaluation, correlation, analysis, synthesis, and generation of recommended values; preparation and publication of the Thermophysical Properties of Matter - The TPRC Data Series, state-of-the-art reports, and critical reviews; technical and bibliographic inquiry services; and current awareness and promotion efforts. TEPIAC covers 14 thermophysical properties and 22 electronic (including also electrical, magnetic, and optical) properties and property groups of nearly all materials at all temperatures. During this 15-month contractual period, the Center has screened 1,000,000 abstracts, scrutinized 112,800 abstracts, identified 21,974 pertinent references, acquired 14,894 research documents, reviewed, coded, and catalogued 8,853 documents, extracted and compiled 4,897 sets of property data from 1,855 data source documents by processing 3,310 selected research documents, responded to 603 inquiries, published the 1,440-page Volume 12 and completed the 1,800-page Volume 13 and the 169-page Supplement to Volume 6 of the TPRC Data Series, completed three special state-of-the-art reports which contain 479 pages, distributed 31,200 copies in eight issues of the "Thermophysics and Electronics Newsletter", and participated in seven conferences and meetings.

Army Materials and Mechanics Research Center,
Watertown, Massachusetts 02172
THERMOPHYSICAL AND ELECTRONIC PROPERTIES INFORMATION ANALYSIS CENTER (TEPIAC) - A Continuing Systematic Program on Tables of Thermophysical and Electronic Properties of Materials
C. Y. Ho, Center for Information and Numerical Data Analysis and Synthesis, Purdue University, West Lafayette, Indiana 47906

Technical Report AMMRC CTR 77-7, February 1977,
55 pp-tables, Contract DSA900-76-C-0860
D/A Project 1T162105AH84, AMCMS Code 612105.11.H8400
Final Report, 1 October 1975 to 31 December 1976

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Key Words
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Electronic properties
Electrical properties
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